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Adapt or Drown—Can the United States Chart a Safe Course Through the Troubled Waters of Energy Security?

by

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Abstract

The United States ensures its national security with the world's most dominant military force. Its strong economy—currently the world's largest—provides the means for this dominance. Cheap oil has fueled the American economic infrastructure for decades—principally from imports of foreign oil. The base of this infrastructure has been the transportation system which consumes over 70 percent of the country's petroleum. Designed primarily around motor vehicles, it has enabled the movement of goods and people for the optimum benefit of the economy and shaped the American way of life. Now rapid industrialization of developing nations has increased demand for oil to a point where remaining excess capacity is relatively trivial. This has resulted in rising oil prices which threaten the continuing strength of the US economy and, in turn, its ability to maintain its national security. This vulnerability demonstrates the close link between US national defense, economic strength, and energy security. The US Energy Information Administration (EIA) asserts in its 2009 Energy Outlook that oil demand will rise by almost 20 percent by 2030. Oil prices will continue to rise as production is increased to meet demand, negatively impacting the United States' gross domestic product (GDP). The driving factors include the increasing costs of producing oil from existing oil fields at a constant rate and the higher costs associated with developing new oil fields. Given this scenario, action must be taken to decrease the direct effect oil has on the US economy. Only by starting now will the nation have sufficient time to overcome organizational inertia caused by naysayers and build the requisite infrastructure to make the goal of energy security through diversification both realistic and achievable.

There is no single solution for solving the Energy Security dilemma in which the United States finds itself. Since it is made up of many different climate zones and has a large regional variation in available resources, it is only logical that the solution to America's energy security problem be multifaceted and diverse. The five following steps are the keys to ensuring a successful outcome:

1. The United States must address the impact of oil prices on the economy now. In order to accomplish this in the short-term, replacement fuels which work with current vehicles must be produced in sufficient quantities to diminish the impact oil has on the economy.
2. Vehicle efficiency must be improved drastically to ensure that the oil currently used produces more "bang for the buck"; lightweight and hybrid vehicles will play a large role in decreasing the transportation system's demand for oil.
3. Future vehicles must divest themselves from oil all together; fuel cell vehicles are one example of a current technology which has the potential of making the internal combustion engine in the transportation system an antique.
4. As the transportation system becomes more and more dependent on electricity, the nation's electrical grid must become more reliable.
    a. Reliability of the grid can be achieved by revamping the grid infrastructure to a "smart grid" which by its nature is more dependable.
    b. The grid must move away from centralized power production and decentralize—it is much harder to physically disrupt a decentralized power producing system than a centralized system.
    c. Incorporating renewable energy sources into the grid decreases the cost of decentralizing power production capacity and decreases the overall cost of producing electricity. Additionally, renewable energy is an attractive option because renewable resources available in the United States, taken collectively, can supply significantly greater amounts of electricity than the total current or projected domestic demand.
5. Legislation at the national level must both incentivize the development of new technologies and penalize the continued reliance on legacy technology in order for such changes to occur in time.

I. INTRODUCTION

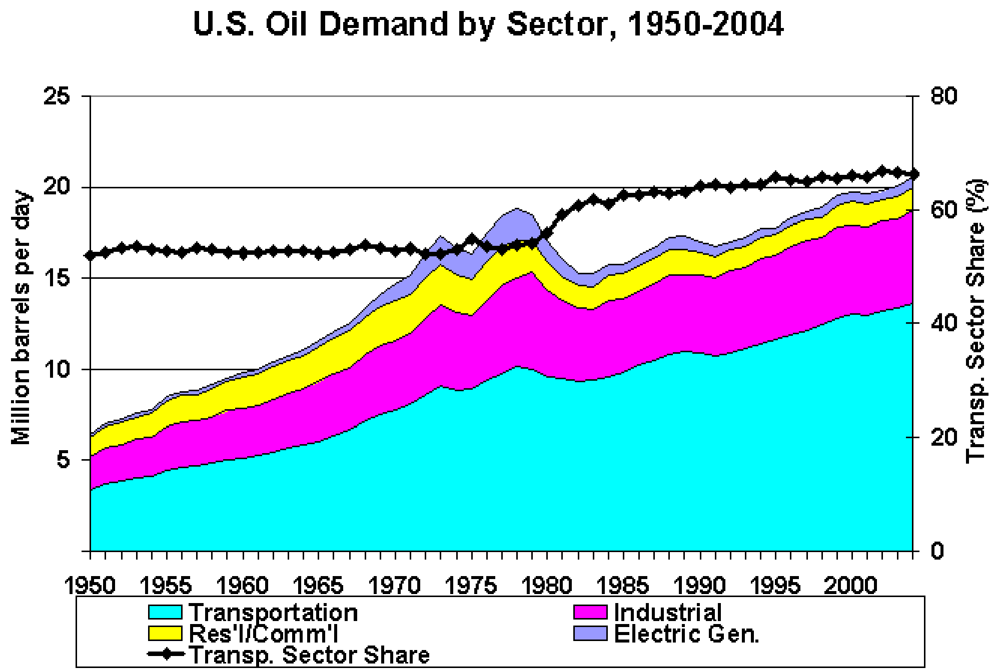
The United States spends more on its military defense budget than the next thirteen top-spending countries combined.[1] A strong economy over the past few decades has enabled the US to establish and maintain the top military defense force in the world, ensuring its national security. However, increasing global competition in consumer markets and competing demand for a limited pool of resources threatens its continuing economic health. Fueling any prosperous economy is energy—energy for transportation, energy for manufacturing, energy to enhance living conditions, etc. It is no coincidence that in becoming the world's largest economy, the US has the unenviable reputation of consuming almost 25 percent of the world's resources with just under 5 percent of the world's population (calculated using 2009 US Census Bureau Data). Much of this resource allocation is dedicated to energy production in the form of fossil fuels such as oil, coal, and natural gas. For many years this country has been able to acquire these natural resources relatively easily. With developing countries such as China and India seeking to become economic superpowers, coupled with their rapidly growing populations, these resources are in higher demand while supply has remained relatively unchanged. It is this competition that poses an imminent threat to the American economy and the US ability to maintain its national security.

End of Cheap Oil

Cheap oil has fueled the American economic infrastructure for decades. While oil has historically been used in lanterns and as a heating fuel, its rise to preeminence coincides with the development of the motor vehicle. As urban and industrial areas began to rapidly expand

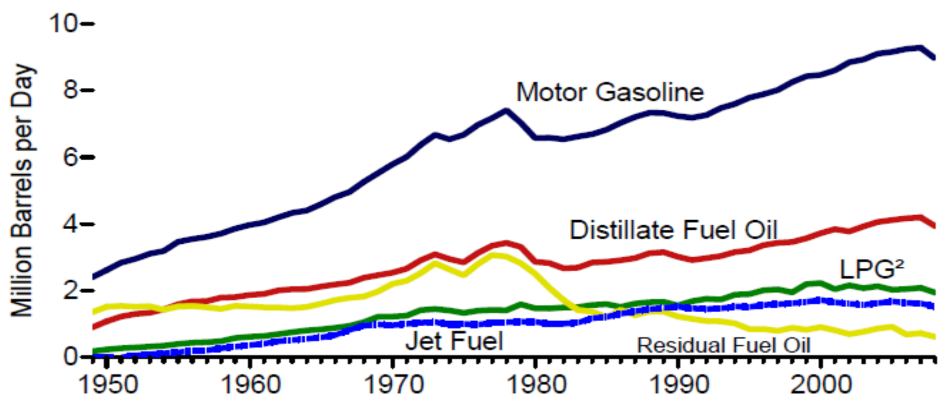
following the industrial revolution, a transportation system was needed to move goods between population centers and existing rural areas that could cover vast distances. Improvements in manufacturing made cars and trucks more abundant and the country's nascent road networks expanded and matured. In the mid to late 1920s, the US government provided aid for "farm-to market" roads and by the 1950s trucks competed favorably against railroads for transport of goods. This launched America's dependence on roadways for transportation. These roadways also allowed people to live further from work than was possible in the past. Suburbia and the associated American dream of owning a home away from the "hustle and bustle of the city" owes its genesis to the automobile and, by extension, oil. Today, most of the products and goods consumed by the average American are centrally grown, raised, or manufactured then moved to stores and markets through a robust road, air, and rail system enabled by oil. In 2004 the US Department of Energy (DOE) reported that the transportation system accounted for just over 40 percent of the petroleum consumed in the United States (see Figure 1). By 2008, the DOE revised their report (see Figure 3) and estimated that the transportation system consumed 13.7 million barrels per day—accounting for 71 percent of all petroleum used in the country. Further examination (Figure 3) also shows that 95 percent of all energy used in the transportation system is provided by oil. Of the 13.7 million barrels of petroleum used daily for transportation, (Figure 2) approximately nine million barrels per day—almost 66 percent—were consumed in the form of gasoline.

Figure 1



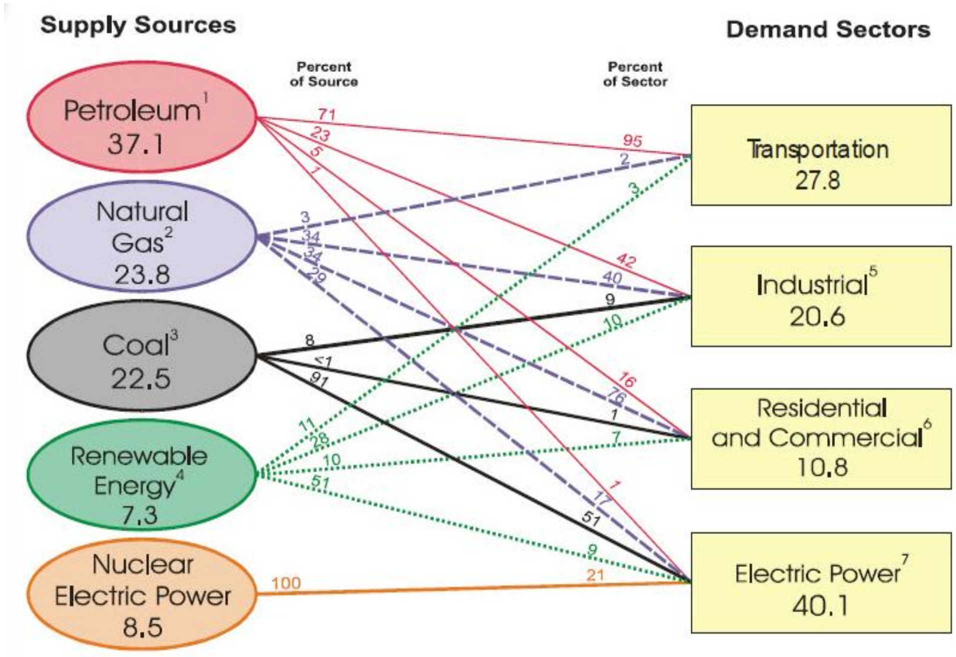
Source:http://www.eia.doe.gov/pub/oil_gas/petroleum/analysis_publications/oil_market_basics/dem_image_us_cons_sector.htm

Figure 2



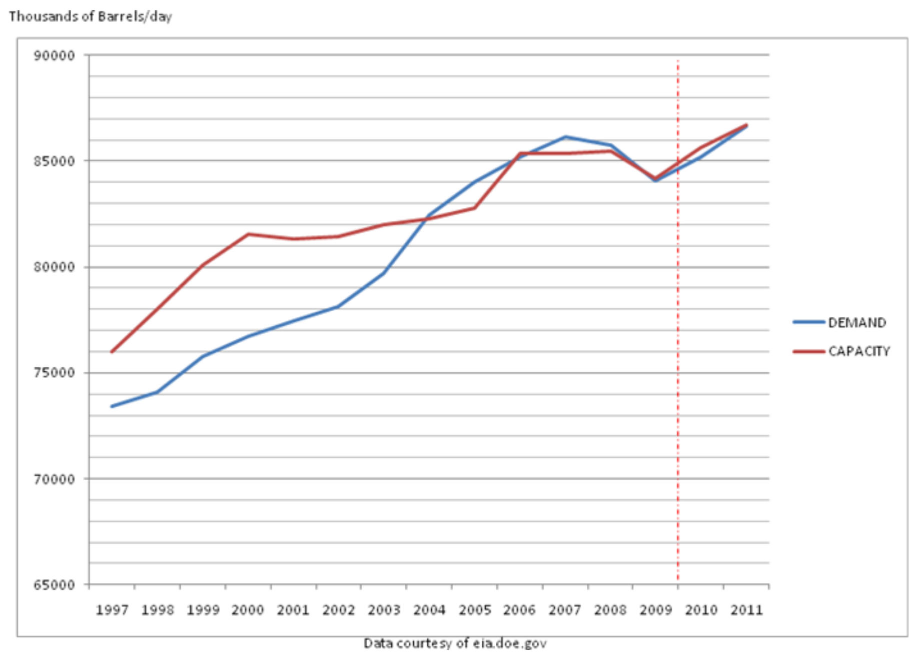
Source: http://www.eia.doe.gov/oil_gas/petroleum/info_glance/petroleum.html

Figure 3



Source: http://www.eia.doe.gov/emeu/aer/pecss_diagram.html

Figure 4



Compiled from data found at: http://www.eia.doe.gov/emeu/aer/txt/ptb0509.html; http://www.eia.doe.gov/oiaf/demand.html

With US transportation so dependent on oil, cheap oil is the key to a flourishing economy. Oil is only cheap so long as it remains available in abundance or, in economic terms, supply exceeds demand. Unfortunately, (see Figure 4), demand for oil has been increasing annually while global production capacity has only kept up by the slimmest of margins. As this trend continues, the United States will find itself in increasing competition with other nations for the very substance which drives its economic engine. Many Americans are slowly becoming aware that the days of cheap oil are in the past yet meaningful attempts to wean the economy from oil have mainly been relegated to political diatribe. Continued reliance on oil not only affects the well being of individual Americans, but also jeopardizes the US economy—the heart of its national power. Lessons can be drawn from countries such as Venezuela where 70 percent of the electricity comes from hydroelectric power. Despite revenue from its extensive oil exports, its economy is struggling as recent droughts have diminished its hydroelectric capacity.[2] Likewise in Haiti, wood is the principle source of energy accounting for almost 70 percent of energy consumption in 2006.[3] This reliance resulted in the virtual denuding of Haiti's forests and contributed to Haiti being the poorest nation in the Western hemisphere. Although the United States is not presently in such a dire situation, to chart a proverbial course through the "troubled waters" of energy security, the country will need to slowly diversify its energy portfolio thereby supporting the nation's economy with a more stable and resilient foundation.

Research Question and Thesis

The time has come for the United States to acknowledge that a continued dependence on oil as the primary energy source for transportation is foolish and new technologies that decrease oil dependence must be nurtured to ensure the continued security of the nation. Of primary concern is determining what technological options are available to the United States to diversify

its energy portfolio and what concurrent legislative actions are required to make this both feasible and timely. An ideal end state for the US energy portfolio would encompass balanced energy sources across the transportation and electrical production systems—with no single source superseding others in importance. It is important to mention that this paper will not advocate for or against the use of foreign oil—oil regardless of its source has associated risks. However, since this paper does focus on energy security from the perspective of the United States it must address certain inherent risks associated with dependence on oil which comes from unstable parts of the world or from countries which are ideologically incompatible. Ultimately this paper will argue that oil should be only one of many energy sources used in the United States—diminishing the ramifications associated with scarcity. In order to accomplish the goal of energy security through diversification in sufficient time, national leaders will need to carefully craft legislation which both incentivizes research into new technologies and more importantly speeds their commercial development.

II. BACKGROUND

Making headlines recently has been the Obama administration's support to lifting the moratorium on drilling for oil in US coastal waters. [4] A move intended to decrease the country's dependence on foreign oil it also increases current supplies. This measure however is only a temporary solution to challenges facing energy security. This increase in domestic oil is estimated to make a relatively small contribution (130 million barrels[5]) to the overall supply. It cannot stem the tide of forces driven by international politics and global competition that will make oil more costly to obtain.

Present Situation

The United States has been importing foreign oil for decades. Sufficient production capacity existed in the past to make up for localized disruptions in the oil producing countries of the world. Now, rapid industrialization of developing nations has increased demand for oil to a point where remaining excess capacity is relatively trivial. Most oil producing countries are currently operating at almost 100 percent of available production capacity (Figure 4); very little excess capacity exists to make up for unforeseen shortfalls or demand increases. With minimal excess production capacity remaining, seemingly small changes in the world's oil supply can impact the global market.[6] Such a disruption could come from destruction or damage to a major oil production facility. It is this capacity shortfall—the game-changing variable—that threatens American energy security and creates national security challenges that need to be addressed. Clearly this reliance on other nations is unsettling as another state could use it as leverage to meet their own interests. Furthermore, "oil is traded on a world market, and the lack of excess global production makes that market volatile and vulnerable to manipulation by those who control the largest shares."[7] Almost 75 percent of the oil in the world is owned by national oil companies. These nationalized oil companies do not necessarily follow market forces—political goals may take priority over maximizing profits.[8]

Yet, even at the most benign end of the spectrum, when oil is not intentionally wielded as an economic instrument of power, the United States is still held hostage by fate. Natural disasters and human error can shut down oil production just as efficiently as a smart bomb. Should an earthquake, lightning strike, or employee negligence cause a catastrophic incident at a large oil production facility anywhere in the world, the US would still find itself economically wounded as it did when hurricanes cut oil production by an estimated 1.4 million barrels per day

in the Gulf Coast—almost 10 percent of the daily domestic oil consumption.[9] Fortunately most damage to the refining and production infrastructure was reparable and most facilities were operational within 60 days after the hurricane passed. Had the destruction been more widespread the nation's 727 million barrel[10] strategic oil reserve would not have been sufficient to buffer the delta between supply and demand. Whether intentional or unintentional, cutting the US oil supply in any significant amount could cripple the economy. Action needs to be taken to not only decrease US reliance on foreign oil but also on oil in general.

What the Future Holds

The EIA asserts in its 2009 Energy Outlook that oil demand will rise by almost 20 percent by 2030, reaching 107 million barrels per day.[11] In order to meet this increase an additional 22 million barrels per day need to be produced—almost three times the amount of oil Saudi Arabia currently produces. This does not take into account replacing lost production in oil fields that are in the twilight years of their existence. To make matters worse, non-Middle East oil reserves are being depleted more rapidly than those of Middle East producers. According to some estimates, this leaves the Middle East with over 80 percent of global oil reserves by 2020.[12] The significant leverage Middle Eastern countries will have over other nations at this point would be unprecedented. These nations would have the ability to wield their natural resources as economic weapons—denying other countries access to vital resources to influence change. These are powerful tools which can and have been used to reduce American influence and freedom of action around the globe.[13] If one considers that many oil-rich nations have strained relations at best with this country—and some are openly hostile—it appears that the US is in a tenuous position. "Major energy suppliers—from Russia to Iran to Venezuela—have been increasingly able and willing to use their energy resources to pursue strategic and political

objectives."[14] A quick scan of news headlines in recent years provides ample evidence that countries are not shy about such tactics:

> Fears are mounting that Russia may restrict oil deliveries to Western Europe over coming days, in response to the threat of EU sanctions and NATO naval actions in the Black Sea;[15] A realistic US policy toward Venezuela will also contain an adequate plan for addressing US energy dependence, since President Chávez treats his nation's oil resources as a pressure tool and economic weapon.[16]

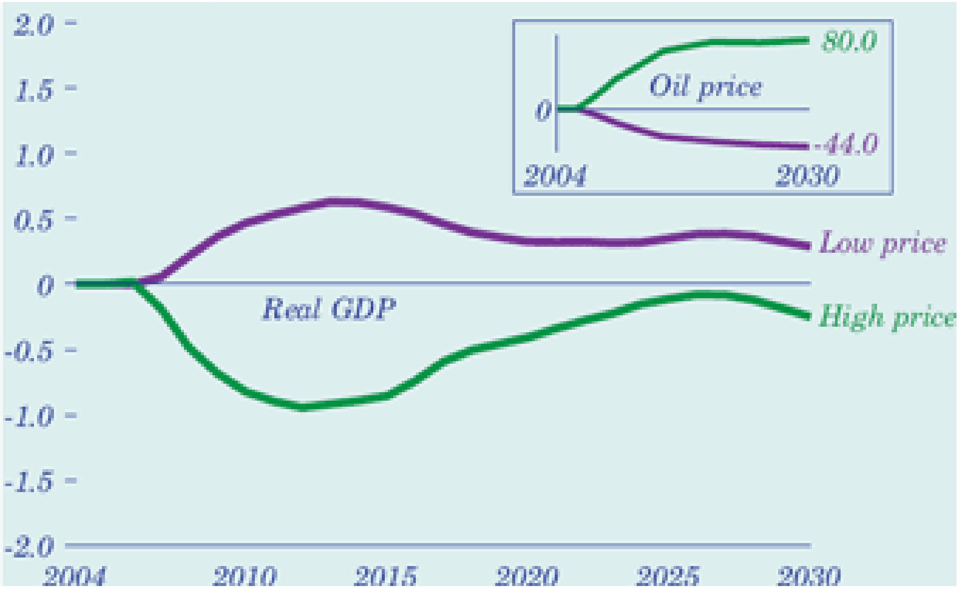
This kind of leverage over United States foreign policy cannot be tolerated and must be addressed.

Not Enough Oil to Go Around

While the preceding sections illustrated how foreign governments and random acts can limit the global oil supply, existing economic forces are also inexorably pushing oil prices higher. Some argue that oil is not in any danger of becoming scarce and point to the peak oil debate to prove their argument. They argue that peak oil advocates have proclaimed "the sky is falling" for some time, yet to date global oil production has continued to increase as new production methods are fielded and untapped oil fields are brought online. Various experts from multiple fields estimate that crude oil production will peak eight to 20 years into the forecasted lifespan of an oil field. They argue that dire effects on world oil prices are likely to follow these peaks. However, the time for these peaks has passed yet dire effects have yet to occur. The real issue is that demand for oil is outpacing supply leaving very little excess capacity to account for production shortfalls.

Oil prices will continue to rise as production is increased to meet demand, negatively impacting the United States' gross domestic product (GDP). The EIA has projected that the forecasted 80 percent increase in oil price will cause a 44 percent drop in US GDP by the year 2030 (see figure 5).

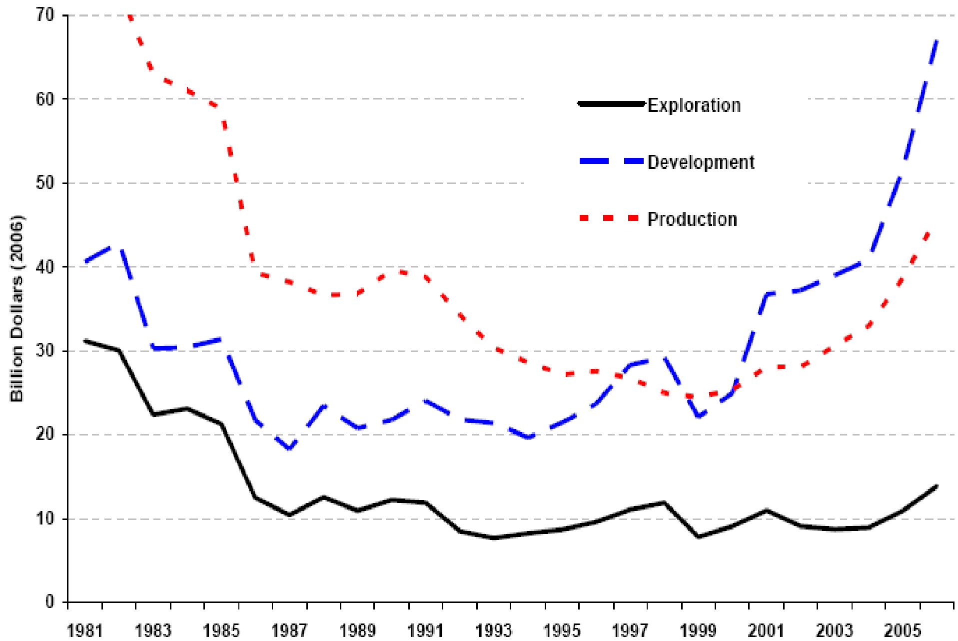
Figure 5



Source: http://www.eia.doe.gov/oiaf/aeo/otheranalysis/aeo_2006analysispapers/efhop.html

The driving factors behind this projection are the increasing costs of producing oil from existing oil fields at a constant rate and the higher costs associated with developing new oil fields. According to a paper written by John H. Wood, Gary R. Long, and David F. Morehouse at the EIA, "All or very nearly all of Earth's prolific petroleum basins are believed identified and most are partially to near-fully explored. All or nearly all of the largest oil fields in them have already been discovered and are being produced. Production is indeed clearly past its peak in some of the most prolific basins."[17] Extreme environmental conditions such as deep water, arctic conditions, and seismic instability make production from the most promising new discoveries dangerous and costly endeavors.[18] These conditions have driven and will continue to drive oil prices higher as cheap oil becomes scarcer—Figure 6 graphically demonstrates this dramatic and continuing jump in costs.

Figure 6



Source: Energy Information Administration, Form EIA-28 (Financial Reporting System).

Source: http://www.eia.doe.gov/neic/infosheets/crudeproduction.html

As stated earlier, the US economy thrives on an assumption that relatively cheap oil will always be available. This inherent weakness within the largest economy in the world was acknowledged during a State of the Union address (given on January 23rd, 1980) when President Jimmy Carter stated: "Let our position be absolutely clear: An attempt by any outside force to gain control of the Persian Gulf region will be regarded as an assault on the vital interests of the United States of America, and such an assault will be repelled by any means necessary, including military force.[19]" The United States found itself so vulnerable to Communist designs for the Persian Gulf region that it committed its military to defend the area from all threats. Some 30 years later the country still finds itself wed to this doctrine and continues to pour blood and treasure into the Middle East to secure access to oil. This continued waste of national power, both economic and military, could leave the country in a position where it once again has peer competitors or, even worse, is eclipsed by another nation. Granted, such a reality is still many

decades in the future but it is inevitable unless the United States can somehow find a way to conserve its national power.

In order to prevent this possible future, action must be taken to decrease the direct effect oil has on the United States economy.[20] To accomplish this goal in the short-term, it will be necessary to sufficiently diversify energy sources used to feed the transportation system and mandate manufacturing changes for the automobile industry. Looking further into the future, the country must make serious strides in diversifying and modernizing its electrical production system in order to decrease overall dependence on fossil fuels while simultaneously increasing the grids' resilience.[21] Only by starting now will the nation have sufficient time to overcome organizational inertia caused by naysayers and build the requisite infrastructure to make the goal of energy security through diversification both realistic and achievable.

III. AVAILABLE TECHNOLOGIES

The United States transportation system is the single most vulnerable target of oil production shortfalls. When looking at solutions to diversify transportation energy sources in America, biodiesel and ethanol inevitably enter the discussion. Supported by legislation and government subsidies (corn and vegetable oil in the US) they are proven and applied technologies. However, biodiesel and ethanol have not been able to replace gasoline to date. This has encouraged continued innovation in these and other technologies to reduce or eliminate transportation's dependence on oil. With research and development moving forward additional issues, specifically in electrical production, have surfaced. It proves that there is no single solution but rather a combination of approaches that will prove the best answer for the US transportation system.

Biodiesel and Ethanol

Discussions surrounding biodiesel and ethanol tend to generate a polarizing debate with three primary camps: those that argue against biodiesel and ethanol completely; those that argue for biodiesel; and those that argue for ethanol. The first camp asserts that biodiesel and ethanol are not being produced fast enough to be considered a significant option for replacing gasoline or diesel. Ethanol is currently made from crops which produce small quantities of fuel then must be replanted and harvested at some point in the future. This delay from planting to fuel production makes ethanol insufficient as a complete replacement for gasoline. Biodiesel production also shares some of the same production concerns since it is currently made from a variety of natural crops including: rapeseed, soybean, mustard, flax, sunflower, canola, palm oil, hemp, jatropha and waste vegetable oils. This ties production rates to crop growth cycle. Competing uses for these crops would limit theoretical production rates to approximately 100 million barrels per year (or less than 7 thousand barrels per day).[22] New sources of vegetable fat are required to make the production of biodiesel realistic. One of the most promising sources is algae. Scientists are working on ways to combine different strands of algae to increase carbon oxide (CO_2) uptake while increasing oil content. Some have even theorized that positioning algae farms (the algae is contained in gas permeable bags which intake CO_2 and release oxygen) near heavy CO_2 pollution sources could increase the yield of algae crops while simultaneously improving air quality in industrial areas.[23]

The second argument in the biodiesel/ethanol debate can be viewed as an extension of the first argument—the impact ethanol and biodiesel production has on the availability and cost of food. The competition between food and fuel decreases the available resources available for ethanol and biodiesel production. It also decreases the amount of food available for human

consumption. Some of the third and fourth order effects of constraining food crops such as corn can lead to decreased feed available for farm animals, increasing the cost of meat and dairy products. One solution, algae, has been discussed for decreasing the dependency of biodiesel production on crops—a similar solution is needed for ethanol. According to the Energy Information Administration (EIA):

> Ethanol can be produced from any feedstock that contains plentiful natural sugars or starch that can be readily converted to sugar. Popular feedstocks include sugar cane (Brazil), sugar beets (Europe), and maize/corn (United States). Ethanol is produced by fermenting sugars. Corn grain is processed to remove the sugar in wet and dry mills (by crushing, soaking, and/or chemical treatment), the sugar is fermented, and the resulting mix is distilled and purified to obtain anhydrous ethanol. Major byproducts from the ethanol production process include dried distillers' grains and solubles (DDGS), which can be used as animal feed. On a smaller scale, corn gluten meal, gluten feed, corn oil, CO_2, and sweeteners are also byproducts of the ethanol production process used in the United States.[24]

There is an alternative to using crops for the production of ethanol. Through a more complex process, plants and other biomass residues such as waste wood, forestry residue, paper and pulp liquors, and agricultural residue can be turned into fermentable sugars.[25] Low cost alternatives to crops could yield significant quantities of fuel-quality ethanol without negative impacts to food markets. The only downside to producing ethanol from other biomass is the increased capital costs to build processing facilities. One energy information agency estimated that a standard ethanol production facility geared towards converting corn into ethanol would cost $65 million to build compared to $375 million for the less traditional facility which would turn waste biomass into ethanol. With a potential fivefold increase in start-up costs, a government incentive or funding provided by either the government or venture capital would make the possibility of this facility more likely a reality. Another alternative to creating ethanol uses waste sludge from sewage treatment facilities—biosolids are removed from raw sewage and used as the feedstock to create ethanol.[26] Not only does this process turn one of society's necessary evils into a

reliable alternative to gasoline, but it could also create an income stream for municipalities—decreasing the overall cost for services to the average citizen.

The final argument is that diesel fuel does not have the market share that gasoline commands and that any solution must focus on gasoline (see figure 2). While this might be true for now, diesel technology has improved dramatically. High-end car manufacturers such as Mercedes, BMW, and Jaguar have already begun to mass market diesel vehicles promoting their fuel efficiency and environmental benefits. These vehicles have been proven to produce similar mileage ratings as smaller cars powered by gasoline. If this trend continues, diesel market share could increase among average commuters. Additionally, a majority of the goods transported in the United States move by truck and train. These vehicles are almost exclusively powered by diesel and insulating them from price fluxes in petroleum would go a long way to protecting the US economy from oil price volatility.

Ultimately, none of the solutions mentioned above are the cure-all for American dependence on oil. Further research and funding is required to field systems which can be scaled for commercial applications. Since producing the requisite +13 million barrels daily consumed by the transportation section is currently impossible with any of these processes, all of the them must be fully exploited and deployed in order for the growing biofuels sector to eventually come close to meeting the US demand for gasoline and diesel. Even if these production methods can never be fully scaled to replace traditional petroleum based fuels, they could create the short-term breathing room needed until more revolutionary technologies can be developed.

Increase Vehicle Fuel Efficiencies

Replacing current fuels with biofuels might be the short-term answer, but America must eventually decrease its ravenous need for fuel. Since decreasing the number of vehicles on US

roadways is impractical, vehicle efficiency is a variable which can be manipulated to decrease the daily consumption of fuel. There are two approaches to increasing fuel efficiency. The first approach continues use of legacy platforms (gasoline and diesel vehicles). By dramatically increasing the efficiency of these platforms, further trade space can be created until long-term solutions are fielded. The second approach is simultaneous innovation of new vehicles which do not require fuel as we understand it now. Such a dramatic leap would be the first since Model-A Fords were introduced in 1903. This would involve developing technologies such as electric-powered vehicles and hydrogen fuel cells.

Increasing vehicle fuel efficiency does not necessarily mean that engines and vehicles must get smaller. Decreasing vehicle weight through the introduction of strong lightweight materials such as carbon fiber in place of traditional steel construction could cut average vehicle weight by almost 60 percent.[27] It is a fact that heavier vehicles burn more fuel—the majority of this extra fuel is expended overcoming inertia when the vehicle is at rest. Few are aware of just how great pivotal weight savings can be—a 10 percent decrease in vehicle weight with no other modification can be expected to net a four to eight percent increase in fuel economy.[28] Weight savings alone on all new production vehicles could decrease fuel consumption in the long term as older vehicles exceed their lifespan. Some might argue that light-weight vehicles are not as safe as their bulky steel siblings.[29] While this may have been true when plastics were used to replace metal automobile parts, it is no longer the case. Composite materials such as carbon fiber are both stronger and stiffer than steel—meaning that cars made of lightweight carbon fiber would actually be stronger and safer than their traditionally manufactured peers.

In addition to decreasing vehicle weight through improved manufacturing techniques, research into hybrid and electric vehicles must continue. Hybrid-electric vehicles combine

gasoline engines and electric motors to improve fuel economy or increase power and performance from smaller engines. They are an excellent replacement for the average commuter's vehicle because they do not require a change in driver behavior. The same infrastructure is used to refuel these vehicles and special attention is not required to plan trips around recharging the vehicle. Improvements in electric drive motors and batteries will allow manufacturers to continue decreasing the size of internal combustion engines used in these vehicles. The primary barrier to the expansion of these vehicles into more markets is the increased production costs which must be passed along to consumers.

Electric-only vehicles, on the other hand, do not use petroleum-based fuels and are far more energy efficient than their internal combustion engine counterparts. According to the federal government, a gasoline engine only converts 20 percent of the stored energy in the fuel to mechanical energy while electric vehicles are able to convert 75 percent of the chemical energy in their batteries into mechanical energy. [30] Electric motors also require far less maintenance than internal combustion engines. Unfortunately, most electric vehicles can only travel around 200 miles before requiring a recharge. Recharging stations are not easy to find in the United States and could be especially difficult to locate on long road trips. Even if one can be located, a full recharge can take between four and eight hours depending on the vehicle—making such vehicles impractical for drivers outside of major population centers. These vehicles are therefore best for commuters who drive fewer than 200 miles a day and spend a majority of their commute in stop and go traffic (the type of driving which shows most benefits from electric vehicles). For these drivers (estimated at 113 million in 2000[31]), not only would there be considerable cost savings, the fuel saved would go a long way to decreasing the country's overall thirst for oil.

With available technologies, the US could cut oil use by 2 million barrels per day by 2015.[32] By aggressively deploying the efficiency improving measures mentioned above taken together with steps to speed the commercial deployment of biodiesel and ethanol the US could sufficiently protect itself from oil price fluctuations by decreasing oil consumption by almost four million barrels per day by 2020—29 percent decrease of current levels.[33] These short and mid-term solutions will provide researchers and manufacturers time to investigate and fully develop new technologies that will lead to the long term divestiture of petroleum-based fuels in the United States.

The only technology available today which could successfully replace the automobile's internal combustion engine is the fuel cell. There are numerous types of fuel cells which use a chemical process to create electricity—the most promising in the automotive industry are hydrogen fuel cells. Fuel cell vehicles are in reality electric vehicles that somehow create their own electricity. Hydrogen fuel cell vehicles use hydrogen, oxygen, and a catalyst such as platinum[34] to release electrons within a fuel cell stack; the resulting current is used to run the vehicle's electric motor. Since hydrogen is the single most common element on earth, it could prove to be a cheap and plentiful fuel source. However, pure hydrogen is not easily found so it must be produced through one of many energy intensive processes which release hydrogen atoms from water.

Hydrogen fuel cell technology is so promising since it replicates the same driving experience that Americans have come to expect and demand. A hydrogen fuel cell vehicle can be driven until it runs out of fuel, refueled quickly and then driven again until more fuel is required—exactly like current gasoline or diesel vehicles. Hydrogen contains more energy than gasoline—roughly 2.6 time as much energy per pound.[35] One drawback is that hydrogen is less

dense than gasoline and given a similar volume (similar size fuel tank) the mass of hydrogen will always be less than that of a given volume of gasoline. This can be overcome by the fact that electric motors are more efficient than internal combustion engines—current hydrogen fuel cell vehicles such as the Honda Clarity received EPA fuel economy ratings of 61 miles per gallon. This two-fold increase in efficiency coupled with expected equivalent cost per mile price of less than $1.50 per gallon by 2020[36] will greatly decrease what the average consumer spends for fuel annually. If fuel cells are such an improvement over internal combustion engines, then why are they just hitting the road now in limited quantities? Besides the fact that fuel cell vehicles are still rather expensive, the entire United States infrastructure is set up to provide gasoline and diesel to motorists. The costs associated with revamping it to support hydrogen distribution could be staggering. Additionally, new facilities would be needed to produce the quantities of hydrogen required to make this automotive revolution a reality. If the hurdles of infrastructure and production costs are overcome, the US could become the least oil-reliant country in the world. Additionally, reducing emissions from vehicles could lead to lower health care costs due to decreases in chronic lung diseases from better air quality and an improved economy driven by consumers with greater buying power. Finally, federal spending might be redirected from defending oil fields in the Middle East to other priorities for ensuring national security.

A consideration that needs to be addressed in applying alternative vehicle technologies such as electric-only and hydrogen fuel-cell vehicles is the increase in demand for electricity. The electricity used to recharge electric-only vehicles and produce hydrogen would today primarily come from some ~600 coal fired power plants[37] or 2,400 hydroelectric power plants[38]. This would just shift dependence from one limited resource, oil, to yet another limited resource--thus not resolving the current energy security dilemma facing the US. These facilities are also

centralized and operate generally independently from one another. This allows for localized disconnects between demand and supply. There have been proposals to resolve this situation but limited immediate impetus to act on any of them.

Smart Grid

> In August 2003, 50 million people living in the Northeast, Midwest, and Ontario were suddenly left in the dark when their electric power failed. More than 500 generating units at 265 power plants shut down—a quiet collapse cascading across the landscape. The blackout is estimated to have caused economic losses of $7 to $10 billion. The trigger for this massive blackout was tragically simple: An Ohio utility had failed to properly trim trees near a power line.[39]

Had this been an intentional terrorist event or a widespread natural disaster, the physical damage to power production facilities could have resulted in a much longer blackout. Attacks using recently discovered threats could result in physical damage to generators attached to the grid[40] leaving parts of the country without a way of generating or transmitting electricity.

Since electrical power seems to be a trend for powering vehicles in the future whether used to create the hydrogen fuel for fuel cell vehicles or to recharge electric plug-in vehicles, the country's electrical grid will become a critical point of failure in the nation's quest for energy security. Considering that a single tree limb was capable of sending 50 million US citizens into the dark ages for a day such a fragile system could be damaged severely by intentional and malicious disruption techniques or by large scale natural disasters.[41] In addition to increasing the resilience of the nation's power grid, its production capacity will also need to grow in order to keep up with increased demand. Increased resilience and additional capacity can be achieved by decentralizing power production, leveraging renewable energy resources, and adopting smart power. Renewable energy sources could provide about an additional 500 TWh (500 trillion kilowatt-hours) of electricity per year by 2020 and about an additional 1100 TWh per year by

2035 through new deployments in favorable resource locations (total US electricity consumption at present is about 4000 TWh per year).[42]

A smart grid could be designed to shunt power around damaged nodes and move excess power from one portion of the country to other parts of the country—decreasing the need for expensive and inefficient power plants (colloquially called "peakers") which are only brought on line during peak load requirements. In this way, energy production costs can be reduced; 30 to 50 percent of the average consumer's energy bill pays for the upkeep of expensive infrastructure which at time sits idle yet still requires upkeep. Inherent to a smart grid design would be diversification of production so that the grid becomes less reliant on a few centralized facilities producing power for a given region—the term used by the Department of Energy is "distributed generation." Disrupting such a network of widely distributed generating facilities that is adaptive—moving energy around the grid as required—would make it virtually impossible to interrupt service for any meaningful duration; local power production could temporarily pick up the load for essential services while an affected area is cut off from commercial power producers.[43]

To better understand electrical production why it must change it is important to look at electricity production today. The current power grid can be viewed as the ultimate "just in time" supply system—at least in concept, since power does not always arrive on time. The infamous rolling blackouts in California and other states during peak loads are a perfect example of production falling behind demand. This lag between supply and demand stems from the current grid's design as a "use as produced" system—it lacks the ability to predict future demand or the capacity to adapt quickly to change.[44] The grid is incapable of storing excess energy and must constantly ramp up and down power generation depending on consumer actions. The

implementation of a smart grid would allow for energy to be stored in various states. This would make renewable energy from intermittent sources such as wind and solar more viable complements to existing production techniques because it would allow excess energy to be stored or used later. Regardless, the current electrical grid could be theoretically upgraded to quickly accept power from any source whether from nuclear, coal, renewable, or a power storage system.[45]

Alternative Electrical Power Sources

Photovoltaic devices have been around for some time using semiconducting materials to convert sunlight directly into electricity. Traditional solar cells are made of silicon and coated with silicon nitrate to boost efficiency. These cells are costly to produce because depositing the silicon nitrate requires special production techniques such as vacuum chambers.[46] In addition, efficiency of traditional photovoltaic cells is only 15 to 18 percent. Since most of the United States receives approximately 5 to 6kWh/m^2/day (with northern latitudes receiving less and the southwest receiving much more) there is a substantial amount of untapped solar energy available (see figure 7). Nonetheless, for photovoltaics to truly become main stream they will need to become cheaper and more efficient.

New technologies are morphing how solar power is harnessed and viewed in application. Recently developed dye-sensitized solar cells utilize a photochemical system to produce energy and therefore can be manufactured in large quantities at a low cost. Additionally, unlike traditional solar panels which are rigid and fragile dye-sensitized solar cells are "mechanically robust" and flexible—making them ideal for deployment in hostile environments. The properties of the cells could allow them to be "gelled," or applied, onto anything—buildings, vehicles, equipment—turning everyday objects into energy producers.[47] Dye-sensitized solar cells' major

drawback is that their conversion efficiency is lower than that of silicon-based cells (approximately 8 percent).[48] Researchers are looking to use nanostructure arrays to enlarge the surface area of these solar cells—thereby increasing energy conversion efficiency in relation to surface area. The question that remains is whether or not this increase in efficiency will negate the cost savings currently associated with production.

Looking to increase solar conversion efficiency, researchers at Sharp Corporation recently broke the record by creating a triple-junction solar cell. Just as the name insinuates, each solar cell is actually a compound cell made up of three solar cells—the result is an energy conversion efficiency rate of 35.8 percent. Production costs associated with this technology which was once reserved for satellites are still high. However, by both increasing batch sizes and crystalline growth rates[49] some believe that this technology could be commercially viable in the near future.

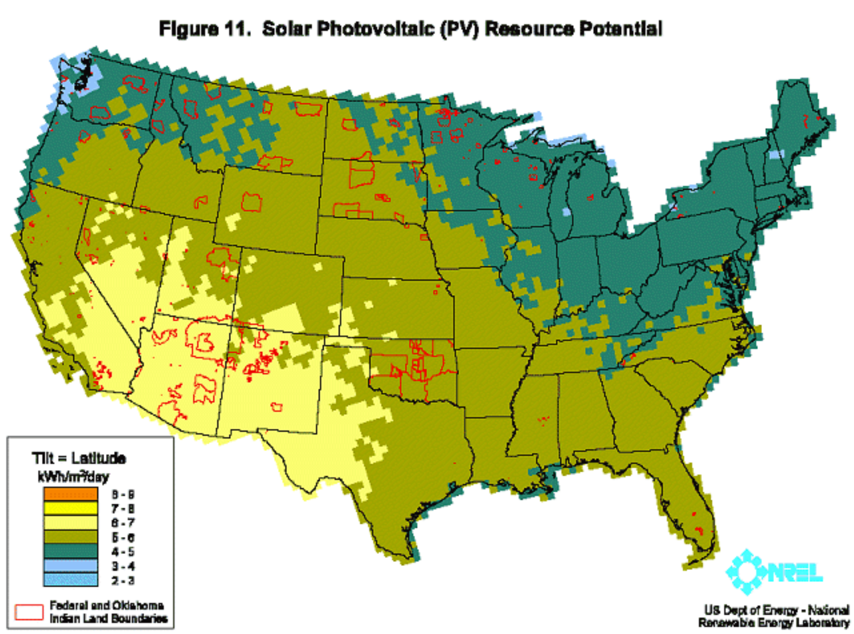
Taking another approach in reducing production costs and increasing efficiency, researchers at Cornell University are looking to replace silicon—an expensive material used in designing solar panels—with carbon. They are using carbon nanotubes instead of traditional silicon to increase the efficiency of converting light to electricity. If this new material can be used to replace silicon solar power could be more economical and within the reach of common consumers.[50]

Yet another technology on the horizon would turn windows into solar panels. Solar company Konarka has developed a transparent solar cell that it hopes will be built onto electricity-generating windows. Konarka makes organic solar cells made from flexible plastic.[51] These solar cells can increase the usable surface area on large buildings for energy production.[52] “But these organic photovoltaics aren't very efficient at converting sunlight to electricity and

won't last as long as a rooftop solar panel, which is typically under warranty for 25 years. Konarka said late last year that it achieved six percent efficiency in its labs…"[53] Both efficiency and durability will need to increase before these products can be deployed in a large scale manner—there will be minimal incentive to install these products in new buildings if the windows will need to be replaced regularly.

The final technological breakthrough currently in development could prove to have the biggest short-term potential. It involves the use of a spray-on hydrogen film and spray-on anti-reflective film in the manufacturing of solar panels. This spray-on method removes the need to use vacuums in the production of solar panels. This process is expected to cut about "$5 million in capital equipment costs per medium-sized factory."[54] This should translate directly into increased production rates and decreased production costs—which could be passed on to the consumer by means of lower pricing. Testing of the process is now taking place and the technology should be available toward the end of 2011.[55]

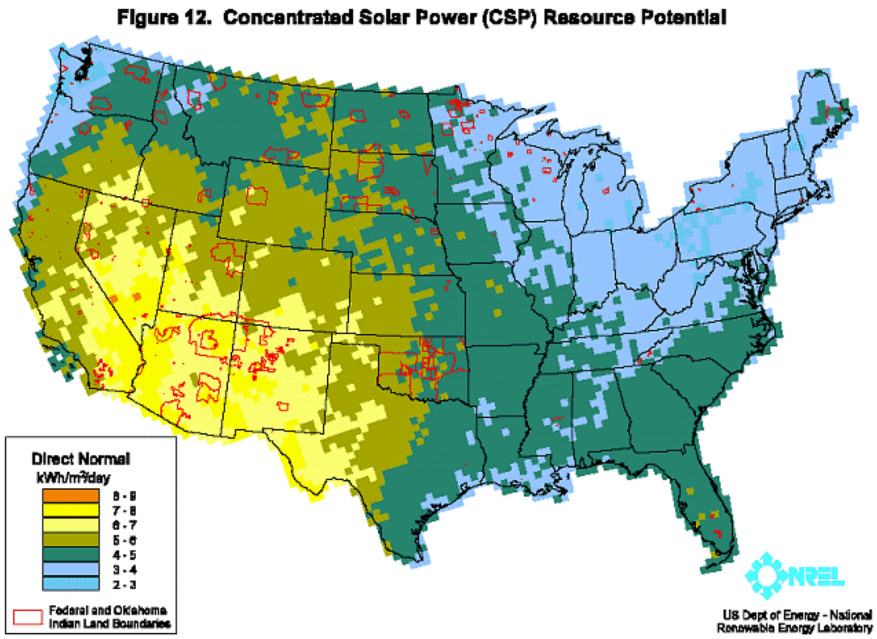
Figure 7



Source: http://www.nrel.gov/gis/solar.html

A second way of producing energy from the sun is through solar thermal energy conversion. Figure 8 depicts the solar resource potential available for the United States, a majority of which is primarily concentrated in the Southwest of the country (upwards of 7kWh/m^2/day). Solar thermal devices harness heat from the sun and concentrate it for various applications. There are two primary methods for utilizing the suns thermal energy. The first method concentrates solar power using mirrors to reflect and concentrate sunlight onto a receiver(s) which collects the sun’s energy and converts it into heat. This heat can then be used to produce electricity through steam turbines that drive generators. According to the United States Department of Energy, there are over six gigawatts of concentrated solar power under contract in the southwestern United States—the equivalent to approximately six nuclear-power plants. The second method of energy conversion uses non-concentrating collectors—flat-plate collectors are the most common type. Flat plate collectors are used when temperatures below 200°F are sufficient—as for heating buildings or pools.

Figure 8



Source: http://www.nrel.gov/gis/solar.html

In addition to solar energy, wind energy is another complementary renewable resource readily available for use. According to the United States Department of Energy:

> People have harnessed the wind to deliver energy for centuries. Today, wind generates electricity that powers millions of American homes and businesses and is one our nation's fastest-growing sources of energy. Taking advantage of this abundant domestic resource to generate electricity helps meet America's growing energy demands while improving our energy security and protecting our environment.[56]

With current technology, wind could produce 20 percent of the countries power requirements by the year 2020 and integrating wind energy into the grid can be done reliably for less than 0.5 cents per kWh. In order to accomplish this certain physical roadblocks must be overcome. Reaching 20 percent wind energy will require enhanced transmission infrastructure, a streamlined siting and permit processes, improved reliability of wind systems and finally, the number of turbine installations must increase from approximately 2000 per year in 2006 to almost 7000 per year by 2017.[57]

IV. LEGISLATION OPTIONS

The status quo presents certain challenges to deploying possible solutions to the energy security dilemma. To counter the organizational inertia and parochialism that often accompany change, regulatory actions and incentives to employ the aforementioned technologies will be required. "For technologies to be accepted in the market they must be clearly attractive—in terms of their performance, convenience, and cost—to investors, purchasers, and users. Regulations and standards that target performance characteristics can do a great deal to spur technological development and help improve market attractiveness."[58] The government must structure future legislation in the form of incentives and sanctions that make new technologies competitive with traditional methods of fuel and energy production. The options available are only limited by imagination, politics and sufficient funding to run the programs.

Incentives

European Union countries such as Germany and Spain have implemented "feed-in tariffs" that function as long-term financial incentives for utilities which buy electricity from renewable sources. The US government could implement a similar tax incentive for corporations within targeted markets. Tax incentives could be structured so that companies benefit from making choices which increase the deployment and utilization of renewable energy sources. For example, energy producers might receive tiered tax advantages based on the percentage of renewable energy in their production portfolio. Another possible incentive used often in government contracts, especially defense, could be cost or risk sharing with a company deploying hydrogen distribution infrastructure. At the individual level, incentives could take the form of government subsidies that keep the price of a commodity or service low. One such

example is biodiesel or ethanol. By subsidizing commodities other than crops for these fuels, consumers could be convinced to switch from traditional gasoline or diesel as biodiesel and ethanol became more available across the country.

In another option, home owners could be given free solar panels by the government or government subsidized companies. The consumer would not own them but would pay a guaranteed rate for power some percentage below the current cost of electricity. In order to qualify for such a program, the home owner might be required to have their home meet a specific minimum energy efficiency rating. In the long run this could decrease overall energy consumption and increase decentralized energy production. Developers and consumers building new homes might also receive similar incentives for using renewable energy sources such as solar or geothermal.

Sanctions

One way to fund the incentives mentioned above is to expand existing "sin" taxes and make better use of cap and trade taxes. Legislators could raise taxes on gasoline and diesel fuel to fund biodiesel and ethanol programs and make them affordable—the extra revenue would be roughly a billion dollars for every penny of additional tax.[59] The next avenue that legislators have at their disposal is cap and trade taxes. Currently, cap and trade taxes apply to the amount of carbon dioxide a utility can put into the air. If a utility company wants to produce carbon dioxide in excess of their quota they must purchase "credits" from the government. The first step that could be taken is increasing the price for producing excess carbon dioxide. This additional revenue could be diverted to the Department of Energy to speed up the deployment of a national smart grid. Once smart grid deployment was far enough along to absorb renewable energy sources, more cap and trade taxes could be structured which mandate that a percentage of

a utilities power portfolio must be renewable.[60] These taxes could be used to fund more incentives and/or research into promising technologies. Additionally, it would artificially create a demand for renewable energy sources and spur the distributed production capacity required to make the national power grid more resilient.[61]

V. RECOMMENDATIONS AND CONCLUSIONS

There is no single solution for solving the energy security dilemma in which the United States finds itself. The first step in finding a solution is acknowledging the fact that the crisis exists. Second, it must be understood that circumstances driven by region and available resources will determine the specific solution for an area. Since the United States is made of many different climate zones and has a large variation in available resources by region, the solution to America's energy security problem will be multifaceted and diverse. It will embrace many if not all of the technologies addressed in this paper as well as numerous others that have yet to become main stream. The five following steps are the keys to ensuring a successful outcome:

1. The United States must address the impact of oil prices on the economy now. In order to accomplish this in the short-term, replacement fuels which work with current vehicles must be produced in sufficient quantities to diminish the impact oil has on the economy.
2. Vehicle efficiency must be improved drastically to ensure that the oil currently used produces more "bang for the buck"; lightweight and hybrid vehicles will play a large role in decreasing the transportation system's demand for oil.
3. Future vehicles must divest themselves from oil all together; fuel cell vehicles are one example of a current technology which has the potential of making the internal combustion engine in the transportation system an antique.
4. As the transportation system becomes more and more dependent on electricity, the nation's electrical grid must become more reliable.
    a. Reliability of the grid can be achieved by revamping the grid infrastructure to a "smart grid" which by its nature is more dependable.
    b. The grid must move away from centralized power production and decentralize—it is much harder to physically disrupt a decentralized power producing system than a centralized system.
    c. Incorporating renewable energy sources into the grid decreases the cost of decentralizing power production capacity and decreases the overall cost of producing electricity. Additionally, renewable energy is an attractive option because renewable resources available in the United States, taken collectively, can supply significantly greater amounts of electricity than the total current or projected domestic demand.
5. Legislation at the national level must both incentivize the development of new technologies and penalize the continued reliance on legacy technology in order for such changes to occur in time.

Conclusion

Some might still wonder why the United States should begin taking action now—looking at some of the most oil-wealthy countries in the world could provide some sobering and much needed incentive to take the proverbial plunge. A number of Arabian Gulf states—including Abu Dhabi, Dubai, Bahrain and Qatar—hope to satisfy a majority of their energy needs through alternative and renewable energy sources instead of oil or other fossil fuels. These countries are slowly decreasing their dependence on petroleum as a source of income and energy; they realize that oil will not last forever and that they must be postured for the future.[62] These countries are investing billions of dollars, made through oil exports, in green technologies through clean-technology investment funds. " 'Abu Dhabi is an oil-exporting country, and we want to become an energy-exporting country, and to do that we need to excel at the newer forms of energy," said Khaled Awad, a director of Masdar, a futuristic zero-carbon city'..."[63] Other countries such as Algeria and Libya have also recognized that oil is not the future. They are investing in large scale attempts to collect solar energy with the intent to one day export this energy to European consumers. [64] [65] If these oil-wealthy nations can envision a world without oil, than the rest of the world must also take heed. They are taking steps now to become energy exporters. Any nation that does not act now will find themselves still beholden to the same unstable part of the world for energy that once controlled all of the oil. The same political and military dialogue that dominates the media and government halls will continue unless action is taken to change the future today.

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